SCHOOL OF

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INDIANA

DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-95/7

Final Report

AN ELECTRONIC SURVEILLANCE AND CONTROL SYSTEM FOR TRAFFIC MANAGEMENT ON THE BORMAN EXPRESSWAY — Part II Calibrating a Simulation Model

Mu-Han Wang and Michael Cassidy

PURDUE UNIVERSITY

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An Electronic Surveillance and Control System for Traffic Management on the Borman Expressway

Part II
Calibrating a Simulation Model

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by
Mu-Han Wang and
Michael Cassidy

Joint Highway Research Project

Project No.: C-36-75A
File No.: 8-9-1

Prepared for an Investigation
Conducted by

Joint Highway Research Project
Purdue University

in cooperation with the
Indiana Department of Transportation

Purdue University
West Lafayette, Indiana
47906

November 20, 1995

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-95/7		

4. Title and Subtitle An Electronic Surveillance and Control System for Traffic Management on the Borman Expressway	5. Report Date November 20, 1995 6. Performing Organization Code
7. Author(s) Mu-Han Wang and Michael Cassidy	8. Performing Organization Report No. FHWA/IN/JHRP-95/7
9. Performing Organization Name and Address Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284	10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Indiana Department of Transportation Indiana Government Center North 100 North Senate Avenue Indianapolis, IN 46204	13. Type of Report and Period Covered Final Report July 1, 1991 through December 31, 1994 14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The purpose of this project was to calibrate a freeway simulation model to emulate traffic operating conditions on the Borman Expressway in Northwest Indiana. To replicate Borman operating conditions, the project adopted Integrated Traffic Simulation (INTRAS), a microscopic, stochastic freeway simulation model. Appropriate input data were developed on geometric, traffic and driver behavior information, based on physical measurements and other available data. The model was calibrated and statistical analysis were conducted to validate the accuracy of the results.

17. Key Words	18. Distribution Statement
freeway, traffic simulation, Borman Expressway, calibration	No restrictions. This document is available to the public through the National Technical Information Service, Virginia, 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The authors of this work gratefully acknowledge the assistance of personnel at the Indiana Department of Transportation. In particular, we thank Messrs. Dan Shamo and Troy Boyd, INDOT Laporte District.

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1. INTRODUCTION

The Borman Expressway in northwest Indiana has the highest average daily traffic demand of any roadway in the state. The expressway, which links Gary, Indiana to Chicago, Illinois, serves an average of over 140,000 vehicles each day. The percentage of trucks in the traffic stream often reaches as high as 30-50%.

The Indiana Department of Transportation (INDOT) has determined that an advanced surveillance and control system is to be implemented on the Borman Expressway. As part of the initial tasks toward deployment of this freeway traffic management system, a computer simulation model was calibrated (i.e., "fine-tuned") to replicate observed Borman operating conditions. The calibrated simulation model will serve as a tool for assessing all proposed future work on the Borman.

1.1. Research Objective

The objective of this project has been to calibrate a freeway simulation model to emulate traffic operating conditions on the Borman Expressway. The computer simulation model will be used to predict impacts created by a host of possible conditions including incident occurrences, maintenance, reconstruction and the deployment of various freeway control and management strategies. The simulation model can be used as a decision-making tool for adopting suitable policies to address operating needs.

1.2 Research Scope

To replicate Borman operating conditions, the project has exploited Integrated Traffic Simulation (INTRAS), a microscopic, stochastic freeway simulation model [Goldblat, 1980; Wicks and Andrews, 1980]. In acquiring needed data to calibrate INTRAS so that the computer model closely replicates observed Borman conditions, several data sources were exploited:

- The Borman Expressway origin-destination survey and ramp counts collected via multiple studies throughout the 1980s. These data were used to estimate the percentages of in-flows and out-flows along the expressway.

- Traffic flow and speed data were collected in 1992 by INDOT and Purdue personnel at nine locations along the expressway. These data were collected for 20-minute periods at each location.

Because of the limited instrumentation then deployed on the Borman, it was not possible to collect traffic stream data at multiple locations simultaneously. To effectively use the data which were acquired in a manner consistent with the logic used by INTRAS to process information, each observation interval were partitioned into observations of smaller time duration (i.e., 2 minutes) and each such observation served as calibration data. Repeated simulations were performed to identify the INTRAS model's "sensitivity parameters" to promote reasonable agreement between empirical observations and simulated outcomes.

To facilitate the use of the calibrated simulation model by INDOT personnel, a "user-friendly" data management program (named BORMAN) was developed and incorporated in the simulation model. This data management program dramatically simplifies and expedites tasks associated with entering input data and executing simulations.

1.3 Report Overview

The report is divided into five sections. Section 1 has summarized background information concerning the objectives and scope of this project.

Section 2 of this report provides a brief introduction of the INTRAS simulation program and summarizes the general information required to code and run the model.

The third report section describes empirical data collection efforts.

Section 4 presents issues associated with calibrating INTRAS, including the outcomes of the calibration process.

Conclusions and discussion concerning potential applications of the calibrated INTRAS model are presented in the fifth report section.

2. THE INTRAS MODEL

Section 2 highlights some of the important features of the INTRAS freeway simulation model.

2.1 Model Features

INTRAS is a stochastic, microscopic computer simulation model developed by the Federal Highway Administration. INTRAS is a vehicle-specific, time-stepping model designed to realistically represent traffic operations on freeways (and surrounding surface streets).

Certain design features of the INTRAS program were especially compatible with the long-term needs for analyses of Borman operations. Most notably, INTRAS incorporates detailed simulation logic for emulating traffic impacts resulting from deployment of freeway surveillance and control strategies. Included here are simulation algorithms representing incident detection and on-ramp metering. The INTRAS model can generate a number of different "measures of effectiveness" for assessing operating conditions including delay, travel time, average vehicle speeds, fuel consumption and energy emissions.

2.2 Model Requirements

Application of the INTRAS model to the Borman Expressway requires input information concerning geometric and traffic stream conditions. Additional input parameters, such as driver characteristics and vehicular performance features, are identified by altering these values through repeated simulations until model outputs closely match observed conditions. A simulation model calibrated to Borman Expressway conditions is the final result of this process.

The following are brief descriptions of input required by INTRAS:

<u>Geometric Information</u>

Geometric information includes section lengths, the number of travel lanes, ramp locations and grades. In this project, required geometric information was acquired from physical measurements in the field, design plans, maps and other related documents.

<u>Traffic Flow Information</u>

Traffic flow information includes freeway mainline demand rates, ramp flows and the composition of vehicle types (e.g. trucks, cars, etc.) in the traffic stream. The calibrated model will be expected to emulate operation under a wide range of these time-variant flow conditions. Every effort was therefore made to collect empirical data under a variety of demand conditions.

<u>Driver Behavior Information</u>

Driver behavior information includes motorist desired average free-flow speed, vehicle acceleration/deceleration characteristics and car following distances. Although in reality these are attributes which the driver/vehicle "carries" over time and space, INTRAS requires single, average values for each freeway subsection. Appropriate values for each parameter are identified as part of the calibration through repeated simulations.

3. EMPIRICAL DATA

Section 3 summarizes the data collection effort used for model calibration.

3.1 Traffic Data Collection

As almost no instrumentation was, at the time, deployed on the Borman, traffic data were manually measured at nine locations using freeway over-crossings for vantage points. Mainline vehicle counts and speed samples were measured for 20 minutes at each location. Observations were partitioned into 2-minute time intervals.

Tables 3-1(a) and 3-1(b) list the observation locations used for eastbound and westbound data collection, respectively. For illustration purposes, means and variances of the 20-minute flows (expressed hourly) are also included in these tables.

Present-day on- and off-ramp demands were extrapolated from INDOT "traffic volume surveys" performed in 1982, 1985 and 1988. These ramp data provided the foundation for model calibration as mainline flows in INTRAS are computed from ramp counts (and the arrival rate at a single upstream origin).

	Georgia	Grant	Broadway	Columbia
Means	3459 vph	2949 vph	3060 vph	3141 vph
Variances	428,810	157,810	175,890	102,544

Table 3-1(a)

Empirically Measured Mainline Flows in Eastbound Direction

	SR 53	Grant	Burr	Columbia	M L King
Means	2649 vph	2826 vph	3078 vph	2877 vph	2655 vph
Variances	78,210	62,792	31,150	21,592	57,150

Table 3-1(b)

Empirically Measured Mainline Flows in Westbound Direction

3.2 Collection of Geometric Information

Required information with regard to the Borman's geometric design features were obtained for each link and node. For each segment, such information included (where relevant) the number of lanes, grades, horizontal curvatures, ramp locations, the lengths of acceleration and deceleration lanes and weaving section configurations. This information was generally determined from design plans and site visits.

4. INTRAS SIMULATION

The fourth section 1) highlights all tasks directly associated with the simulation experiments performed in this work and 2) presents the outcomes of the calibration efforts.

4.1 Coding the INTRAS Model

The INTRAS model uses a scheme of links and nodes to represent the freeway system. Each uni-directional freeway segment is depicted with a link with specified features (i.e., section length, number of lanes, etc.). Nodes are used to represent geometric discontinuities created by ramp junctions, lane drops, etc.

Figures 4-1(a) and 4-1(b) present schematic coding diagrams used to represent the Borman Expressway in eastbound and westbound travel directions, respectively.

4.2 Sensitivity Parameters

Intrinsic to the INTRAS model are a number of so-called sensitivity parameters which significantly impact simulated outcomes. These parameters are 1) motorist desired free-flow speeds; 2) driver gap acceptance criteria; 3) desired car-following distances; and 4) vehicle performance characteristics. These parameters can not be observed directly. Rather, appropriate values for these parameters are obtained through heuristic methods. Namely, parameter values are altered in repeated simulations until simulated outcomes of traffic stream measures (e.g. flows, average speeds, etc.) closely match empirically observed values. This, in short, describes the calibration process [Annino and Russell, 1979; Benekohal, 1991; Kleijnen, 1975].

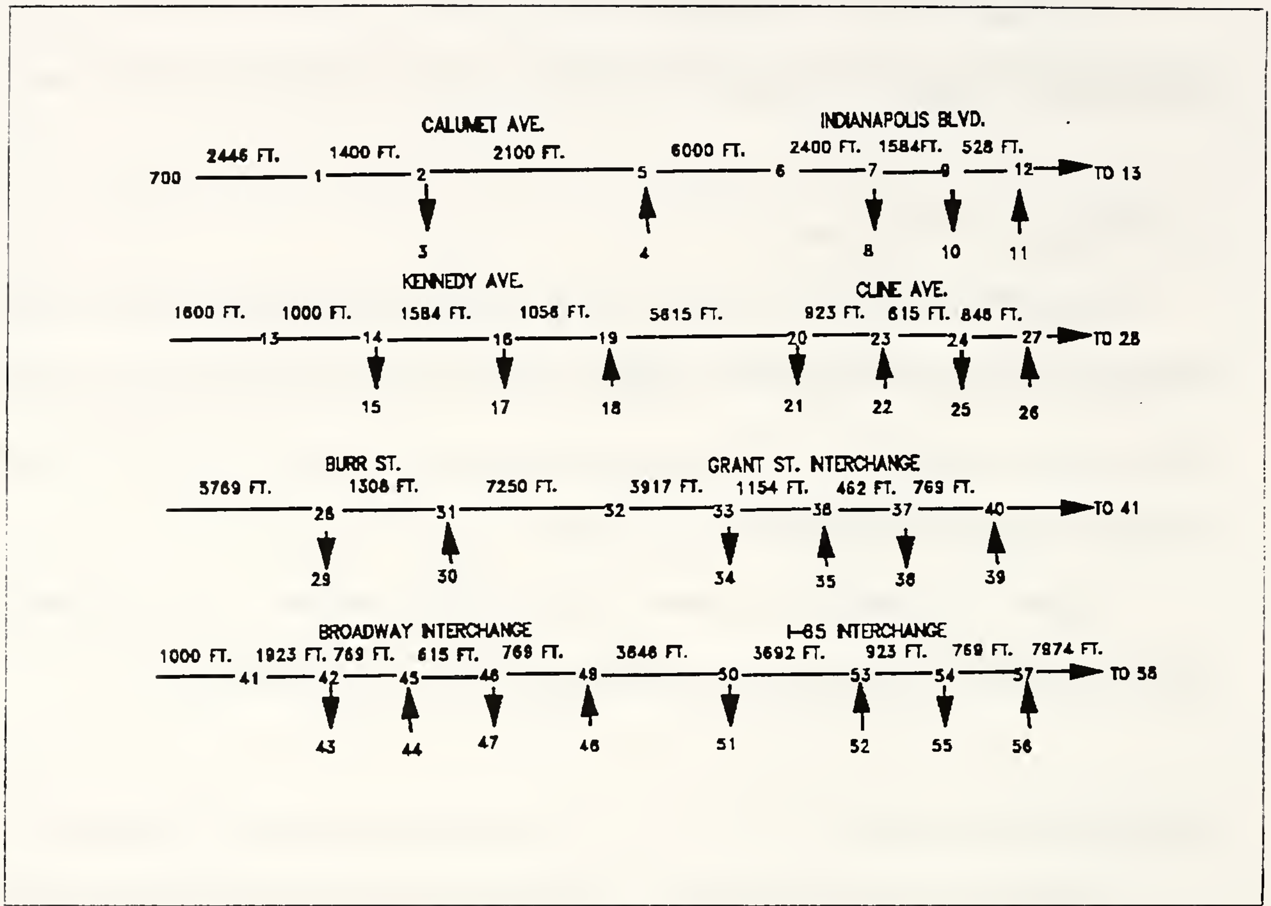

Figure 4-1(a)

Borman Coding Diagram for Eastbound Direction

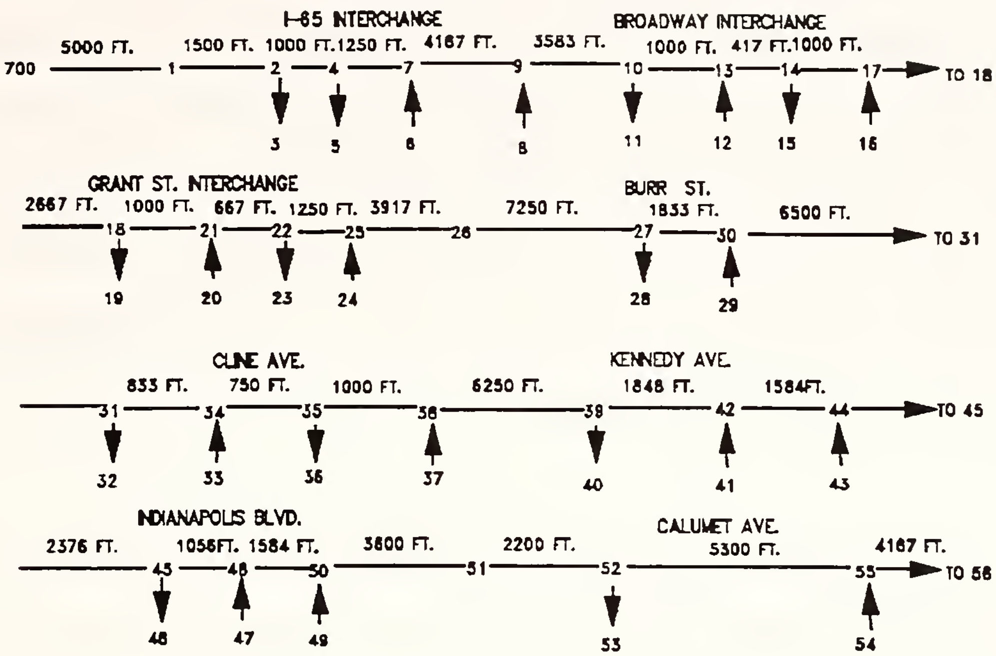

Figure 4-1(b)

Borman Coding Diagram for Westbound Direction

4.3 Model Calibration

Sensitivity parameters were tested through repeated simulations until simulated results were consistent with observed data. Historical on-ramp flows served as input for the calibration process. Agreement between observed and simulated mainline flows and average speeds were the criteria used for assessing the success of the calibration process. Group variance and group mean comparisons [Naylor et al., 1967] served as the statistical tool for evaluating the agreement between observed and simulated values.

Tables 4-1(*a*) and 4-1(*b*) present the group variances for empirically measured and simulated values of mainline flow for each of the nine mainline data collection locations along the Borman. Tables 4-2(*a*) and 4-2(*b*) present group variances for the measured and simulated values of average speed.

Tables 4-3(*a*) and 4-3(*b*) present group mean comparisons between empirical and simulated flows at each of the nine observation locations. Tables 4-4(*a*) and 4-4(*b*) present group mean comparisons of empirical and simulated average speeds in the eastbound and westbound directions, respectively.

We note that the calibration process continued until significant differences (in a statistical sense) did not exist at any of the observation locations. Consequently, the calibration process generated simulated values of flows and average speeds which closely matched empirical

	GEORGIA	GRANT	BROADWAY	COLUMBIA
EMPIRICAL (S_1^2)	428,810	157,810	175,890	236,010
SIMULATION (S_2^2)	331,084	89,612	102,544	192,038
S_1^2/S_2^2	1.295	1.761	1.715	1.229
TEST RESULTS	ND	ND	ND	ND

Table 4-1(*a*)
Comparison of Variances of Mainline Flow (Eastbound)

	SR 53	GRANT	BURR	COLUMBIA	M L KING
EMPIRICAL (S_1^2)	78,210	31,150	104,850	203,275	57,150
SIMULATION (S_2^2)	62,792	21,592	95,740	143,884	43,252
S_1^2/S_2^2	1.246	1.443	1.095	1.413	1.321
TEST RESULTS	ND	ND	ND	ND	ND

NOTE: ND: No significant difference.

Table 4-1(*b*)
Comparison of Variances of Mainline Flow (Westbound)

	GEORGIA	GRANT	BROADWAY	COLUMBIA
EMPIRICAL (S_1^2)	3.3	2.3	1.6	2.0
SIMULATION (S_2^2)	1.17	0.91	0.73	0.81
S_1^2/S_2^2	2.821	2.527	2.192	2.469
TEST RESULTS	ND	ND	ND	ND

Table 4-2(*a*)
Comparison of Variances of Mainline Average Speed (Eastbound)

	SR 53	GRANT	BURR	COLUMBIA	M L KING
EMPIRICAL (S_1^2)	2.0	1.8	2.0	2.0	1.9
SIMULATION (S_2^2)	0.86	1.38	1.07	0.68	1.6
S_1^2/S_2^2	2.326	1.304	1.869	2.941	1.188
TEST RESULTS	ND	ND	ND	ND	ND

NOTE: ND: No significant difference.

Table 4-2(*b*)
Comparison of Variances of Mainline Average Speed (Westbound)

	GEORGIA	GRANT	BROADWAY	COLUMBIA
EMPIRICAL (U_1)	3,459 vph	2,949 vph	3,267 vph	3,141 vph
SIMULATION (U_2)	3,409 vph	2,929 vph	3,078 vph	3,197 vph
T-test	0.173	0.123	1.075	-0.256
TEST RESULTS	ND	ND	ND	ND

Table 4-3(*a*)
Comparison of Means of Mainline Flow (Eastbound)

	SR 53	GRANT	BURR	COLUMBIA	M L KING
EMPIRICAL (U_1)	2,649 vph	2,817 vph	3,110 vph	2,937 vph	2,700 vph
SIMULATION (U_2)	2,694 vph	2,871 vph	2,989 vph	2,943 vph	2,747 vph
T-test	-0.36	-0.71	0.81	-0.03	-0.44
TEST RESULTS	ND	ND	ND	ND	ND

NOTE: ND: No significant difference.

Table 4-3(*b*)
Comparison of Means of Mainline Flow (Westbound)

	GEORGIA	GRANT	BROADWAY	COLUMBIA
EMPIRICAL (U_1)	59.5 mph	60.6 mph	59.5 mph	58.7
SIMULATION (U_2)	60.3 mph	60.4 mph	59.0 mph	58.8
T-test	-0.62	0.40	0.94	-0.18
TEST RESULTS	ND	ND	ND	ND

Table 4-4(*a*)
Comparison of Means of Average Speed (Eastbound)

	SR 53	GRANT	BURR	COLUMBIA	M L KING
EMPIRICAL (U_1)	58.1 mph	59.5 mph	58.6 mph	58.8 mph	59.9 mph
SIMULATION (U_2)	58.4 mph	60.1 mph	57.5 mph	58.0 mph	59.8 mph
T-test	-0.57	-1.02	2.07	1.52	0.15
TEST RESULTS	ND	ND	ND	ND	ND

NOTE: ND: No significant difference.

Table 4-4(*b*)
Comparison of Means of Mainline Average Speed (Westbound)

5. CONCLUSIONS & DISCUSSION

The calibration process identified suitable values for all model sensitivity parameters so that simulated outcomes are consistent with observed operating conditions. Having successfully "fine-tuned" the INTRAS simulation model to replicate Borman conditions, the model can be used for evaluating proposed scenarios, including design alterations, control strategies and traffic management plans, with a reasonable degree of confidence.

The calibrated INTRAS model has been installed on micro computers at INDOT's Laporte District. Personnel have been provided INTRAS User Manual to facilitate the execution of simulation runs. To simplify the otherwise complicated and tedious task of data entry, the research team has developed a user-friendly interface. The interface, which is installed on the INTRAS model in the LaPorte District office, allows users to efficiently enter required input data by responding to prompts. Such input information would typically entail 1) hourly or sub-hourly traffic demands at the mainline origin and ramps; 2) the boundaries of the Borman to be evaluated; and 3) the time duration of the simulation. Proposed or actual changes to the Borman's geometric design can be readily incorporated into the model by referencing the INTRAS User Manual.

COVER DESIGN BY ALDO GIORGINI